

Final Technical Teport

ONR Grant N00014-03-1-0564

Satellite Communication to Research Vessels at Sea: High-Seas ROADNet.

Introduction

Oceanographic research vessels are the laboratories of the ocean sciences playing, an essential role in unraveling the physical, chemical and biological feedback loops that relate oceanic processes to Earth and climate systems. While new remote sensing techniques, smart floating platforms, and autonomous underwater vehicles represent the cutting edge of ocean technology, the U.S. academic research fleet (Table 1) is the primary tool by which oceanic knowledge has been and will be obtained. This fleet will continue to be central to the development of understanding whether directly, by facilitating shipboard oceanic research, or indirectly, by deploying autonomous vehicles, servicing moorings or calibrating remote observations.

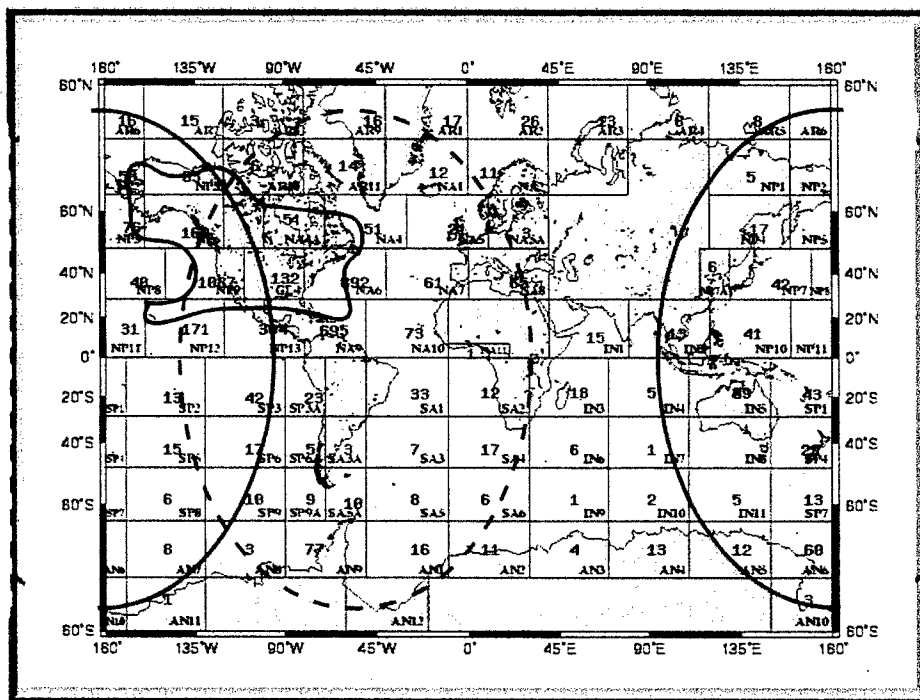


Figure 1. Requests for UNOLS ship use during the period 1998-2003. The numbers in red give the number of requests for ship time in each of these major ocean regions. The solid red lines show the limits of coverage of the existing *HiSeasNet* Teleport. The dashed green and the solid blue line show approximately the expanded coverage provided by the additional Teleport equipment proposed herein.

This grant supported the acquisition of satellite communications systems, now call *HiSeasNet* (www.hiseasnet.net), to provide continuous Internet connectivity for oceanographic research ships and platforms. In the same way access to the Internet is an integral part of nearly every research lab and office on land, extending this access to oceanographic ships - our seagoing laboratories, will have the broadest impact on all seagoing research activities. For the ships, *HiSeasNet* impacts all aspects of seagoing research activities including:

- Transmission of "hot" data in real-time to shore-side collaborators;
- Providing basic communications between the research vessel's scientists, engineers and crew - both email, voice and video teleconferencing;
- Provide valuable and exciting tools for real-time educational interactions between ship-board scientists and teachers and the classroom.

Specifically, this grant provided funds for a major enhancement of the fledgling *HiSeasNet* designed to provide continuous shipboard connectivity to the global Internet for the academic research ships of the University-National Oceanographic Laboratory System (UNOLS, <http://unols.org/>. See Table 1). The UNOLS fleet, operated by some 20 academic institutions in the US, is used to conduct almost all of the seagoing oceanographic research done by US academic researchers, as well as being used widely by US Government scientists.

Until recently communications between ship and shore were limited to radio voice communications and quite limited, low-speed and expensive email systems. For example, the widely used INMAR-SAT satellite terminals are relatively inexpensive to buy, but the tariffs are high when calculated on a \$/MB basis. While it can provide sustained throughputs up to 8 kBytes/s for file transfer type applications at a cost of about \$25/MB, more typical Internet usage costs are about 4 times this amount - nearly \$100/MB.

Recent advances in antenna and modem technology coupled with decreasing costs for communications circuits has now made it practical to use continuous intermediate-speed (>64 kbps) duplex communications to provide Internet services to oceanographic ships at sea for delivery of data ashore and communications with scientists and engineers on the ship.

With funding from the NSF, and the State of California, we implemented the first stages of *HiSeasNet*. In early 2002 we installed a satellite terminal on the *R/V Roger Revelle*, and leased service from a commercial teleport to provide a 64 kbps full-period connectivity between the ship and the public Internet. Funds from this grant supported the installation of a 7m Teleport or hub antenna at the San Diego Supercomputer Center, with coverage over much of the Pacific Ocean (see Figure 1) and ships' systems for a second SIO ship, the *R/V Melville*, and the *R/V Thomas Thompson* operated by the University of Washington.

As an example of typical research use of large oceanographic research vessels, we summarize below the cruises and scientific parties who benefited directly and immediately from *HiSeasNet* during the first year of operation of the system on the *R/V Roger Revelle*. Comments from many of these individuals are included in section C.

Cruise Purpose	Chief Scientist	Scientific Compliment
Student Training	MacDonald, UCSB	3 UCSB scientists, 10 UCSB undergrads, 7 UCSB grad students, 1 sci. each from SDSU, U. of So. Carolina and OSU, 3 foreign observers (1 UABC, 2 CICESE), 2 UABC grad students, 3 SIO technicians, 1 SDSU technician.
Multi-Diciplinary (2-ship)	Wheeler, OSU	OSU - 7 scientists, 11 technicians, 3 grad students. 1 WHOI scientist, 2 WHOI technicians, 2 SIO technicians.
Show-and-Tell CAL-COFI	Goericke, SIO	Various politicos, scientists and techs to who-and-tell, etc. - incl. Kennel, Knox,
California Coastal Currents	Venrick, SIO	28 SIO scientists, 3 SIO techs, 1 scientist Point Reyes Bird Observatory, 1 USC grad student, 1 observer, 1 K-12 teacher
ATV Testing	Zumberge, UCSD	4 SIO scientists, 7 SIO techs, 3 Oceaneeering Technology techs.
Naval Hydromechanics	Terrill, SIO	2 SIO scientists, 7 SIO technicians, 3 UCSD undergraduates, 2 Caltech scientists, 1 Univ. of NH scientist, 3 Kongsberg-Simrad technicians, 1 Viosense tech.
Hawaiian Ocean Mixing Experiment	Luther, UH	2 UH scientists, 1 UH tech, 4 UH grad students, 2 UH undergrads, 1 OSU scientist, 1 OSU tech., 2 SIO techs
Hydrographic and Biogeochemical	Karl, UH	10 UH scientists, 2 SIO techs.
Ocean Acoustics	Porter, SAIC	3 SAIC, 1 SIO, 2 UW, 2 UDeI, 1 NUWC, 3 UNH, 2 SPAWAR. Technicians - 4 SIO, 2 UW, 1 SSI, 1 RESON, 1 SPAWAR, 1 UDeI. Grad students - 1 SIO, 1 UDEL
Biocomplexity	Michaels, USC	1 SIO, 3 UH, 5 UMd, 6 USC, 1 WHOI, 4 SFSU, 1 Ga.Tech., 2 UConcepcion, 1 UCLA. Grad students - 1 UMd, 1 UGa, 1 UCLA, 5 USC, 1 Princeton, 1 SFSU, 1 UCSB. Techs - 1 SFSU, 4 USC, 3 SIO
Marine Geophysics	Chadwell, SIO	5 SIO scientists, 3 SIO grad students, 2 observers, 3 volunteers, 2 SIO techs.
Multibeam Seismics	Lonsdale, SIO	2 SIO scientists, 1 SIO grad student, 7 SIO techs., 3 Mex. observers, 1 Japanese observer, 1 SIO observer
Mooring Servicing & "Teacher at Sea" cruise	Weller, WHOI	1 WHOI, 1 NOAA/ETL, 2 UColo. Technicians - 4 WHOI, 3 SHOA (Chile), 2 NOAA/PMEL, 1 SAIC, 1 NOAA/ETL, 1 NOAA/OGP, 1 Ecuador Navy, 3 SIO. 1 TAMU grad student. 3 foreign observers, 1 US observer (teacher at sea)
Plate Dynamics & Acoustic	Chadwell, SIO	4 SIO scientists, 3 SIO grad students, 3 SIO techs., 1 foreign observer.

B. Description of HiSeasNet.

The use of satellite services for Internet traffic between the oceanographic fleet and shore can be distinguished from other applications by the asymmetry of its traffic pattern. The system requirement is primarily to carry data from the ship to shore, rather than to provide IP services to the ship. This is in contrast to systems designed primarily to deliver data services to

the ship. This fundamental design criterion leads to considerable cost differentials, because it is much more expensive to send information from shore to the high seas than it is to send data from the high-seas to shore with systems of practical design.

There are a number of companies that offer "turn-key" Internet service to ships. A typical customer is a cruise ship line that wants to offer a variety of services to its clientele such as: web access, email, electronic banking and ATM machines, electronic newspaper delivery and video streaming. The basic idea for these customers is to bring "shore to the ship," in contrast to the oceanographic research community which wants to bring the "ship to the shore". In the cruise-ship environment, each vessel receives a broadband outbound multi-cast. Such systems provide high-speed broadcast data delivery, currently up to 2 Mbps per broadcast. The network architecture allows a base station to transmit a large bandwidth carrier to a single ship or to a group of vessels. Each ship receives the entire volume of traffic destined specifically for all the vessels in a particular group. The ship's router selectively filters the information addressed to a particular network, dropping all other traffic. Typical recurring costs for these turn-key systems are about \$10k/month for each ship in the network.

The architecture of the *HiSeasNet* satellite communication system, in contrast, is designed to accommodate multiple ships and oceanographic platforms whose principal traffic patterns will be inbound to the shore. It is based on a "star" configuration, with each ship having a direct satellite connection to the *HiSeasNet* Teleport facility. Communications between each ship and the Teleport is carried on dedicated duplex satellite circuits that can be sized according to requirements or needs of the particular ship's research operation.

In order to provide coverage over the open oceans we have chosen to utilize the global beams of the Intelsat system satellites. This fleet provides coverage of the entire globe at latitudes less than about 74°. For coverage of coastal waters, extending out to Hawaii and over considerable portions of the North Atlantic, we plan to use a single domestic Ku-band satellite.

The use of a single land-based "hub" facility as the center of communications allows the investment in and management of this facility to be shared among all of the ships. Under normal operations, channels will be at least 96 kbps from ship-to-shore and share a 64 kbps (point-to-multipoint) channel from shore-to-ship. The reason for this lack of symmetry has to do with the ship's antenna size relative to the Teleport antenna size - the architecture is designed to make maximum use of leased satellite resources.

For the larger ships, a 2.4 meter radial offset antenna with a 3-axis servo controlled stabilization system is housed in a 3.7 meter diameter radome (Figure B.1). For the smaller regional and coastal ships, the antenna is only 1.2 meters housed in a proportionally smaller radome. The antenna beam direction is locked onto the signal transmitted from the satellite by the 3-axis servo to a precision of better than 0.2 degrees under the following conditions.

- Tangential acceleration < 0.5G in 6 seconds
- Roll stabilization amplitude < ± 25 degrees
- Pitch stabilization amplitude < ± 15 degrees
- Rate (all axes) < 90 degrees/s
- Acceleration (all axes) < 60 degrees/s²

The Teleport (Figure B.2) houses the modems and central router with a direct fiber connection to the main UCSD Internet switch. This router, and related software systems, allow the man-

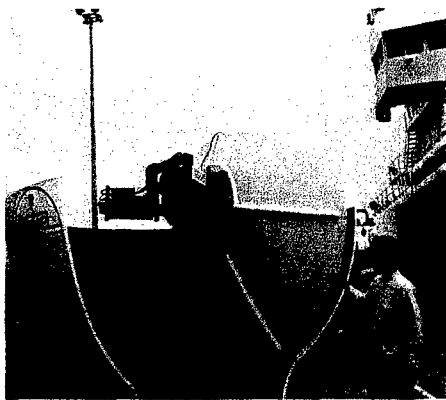


Figure B.1 The left panel shows the SeaTel Antenna with the radome half completed. The right panel shows the C-Band antenna located starboard side aft above the bridge of the *R/V Roger Revelle*.

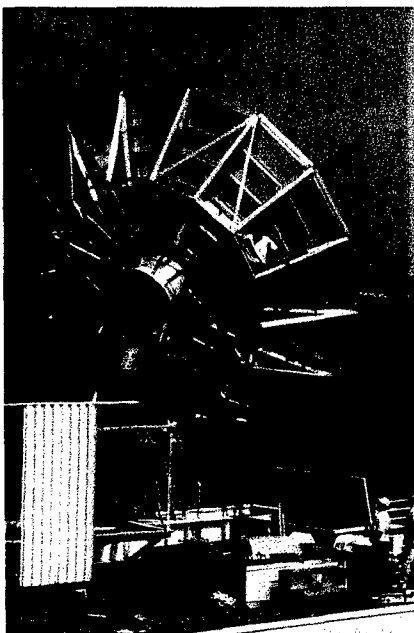


Figure B.2 The hub of the star network, the *HiSeasNet* Teleport, is located on the roof of the San Diego Supercomputer Center. It consists of a 7m antenna, controllers, modems and routers connected directly to the main UCSD Internet switch, providing direct connection to the Internet backbone. By using a single, shared 7m class Earth station at the Teleport, 2.4m antennae can be used on the ships. This minimization of ship-board antenna size is critical due to the more difficult physical environment, requiring specialized motorization and tracking equipment.

agement and control of the shared circuit out to the ships. This allows prioritization of certain applications (FTP or VoIP) over other less critical applications (web traffic), as well as insuring that the bandwidth is distributed equitably and efficiently among the ships. This router also can be used to provide necessary security.

Due to the smaller antenna on the ships, the link from the shore to the ships is the most expensive in terms of transponder power and operating costs. A common shared carrier at a data rate between 64 kbps and 128 kbps is envisioned to support a set of two to four ships. The ships would share several carriers from the central facility, and local routers on each ship would extract their relevant data packets from the received stream.

The modems we are using, Comtech CDM- 550, are low-cost units designed for single channel-per-carrier circuits. They support data rates between 2.4 kbps and 2048 kbps in 1 bps steps insuring that we can tailor our circuit speeds to maximize utilization of leased bandwidth. They implement a recently developed forward error correction technique called Turbo Product Coding (TPC) to decrease significantly the resources required to run the network. This reduces the most expensive part of the system, the transponder lease costs. TPC, theoretically derived in the early 1990s, and now commercially available, allows satellite data transmission using 30% less transponder power than the previously used Reed-Solomon/Viterbi decoding, and 60% less power than Viterbi decoding alone. This is particularly important for use with small antennae where flux density issues are important. This power savings directly translates into reduced monthly operating costs for the satellite transponder, as well as reduced antenna size requirements. A special feature of these modems is the ability to monitor and control the distant end of the satellite circuit.

The modularity of the network design allows for easy expansion of services, in terms of applications, data rates, and number of ships supported. By using IP as the basic protocol, any application based on IP can be added to the services. Increasing the data rates supporting those services can be easily done by simply procuring additional satellite transponder capacity and re configuring the existing equipment. Additional ships can be brought online through the simple addition of another satellite modem at the central facility. Overall, this network allows for flexible adaptation and scalability with regard to services, capabilities, and users.

The current Teleport antenna covers the area shown in the left panel of Figure B.3 (See also Figure A.1).

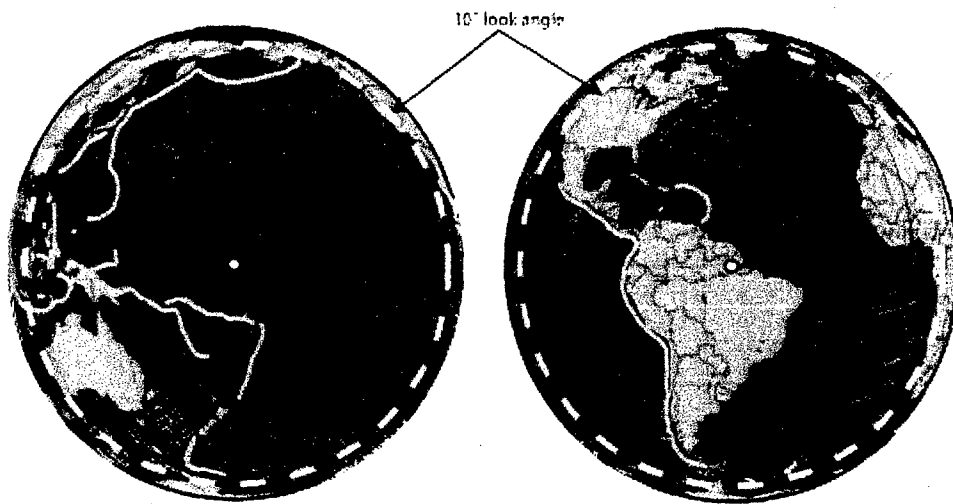


Figure B.3. The coverage offered by INTELSAT 701 at longitude 180° (left panel) and 703 at longitude 53° W (right panel). The dashed white circle indicates the loci of positions with a 10° elevation angle, the practical minimum for good, continuous coverage.

C. Impact of Infrastructure Project

HiSeasNet is implemented as a fully functional IP satellite network based on TCP/IP protocols and Cisco technology. While the shipboard hardware and system architecture are capable of supporting over T1 data rates, the existing links are 96 kbps on the ship-to-shore half circuit. These data rates provide reasonable speed in sending real-time data back to shore-side researchers. This allows the researchers on land to analyze the data and make adjustments to experiments and measurement techniques that can be applied immediately.

The IP transmission basic protocol supports a wide variety of applications in addition to research data retrieval. In addition to the familiar TCP/IP services such as e-mail, telnet, ssh, rlogin, web traffic and ftp, telephone services using voice-over-IP (VoIP), and multi-media services are also provided. (See Table C.1)

While INMARSAT has provided reliable communications at sea for years, the on-demand (dial-up) tariffs preclude extensive use of the system for large amounts of data traffic or extended periods of constant use. Current commercial "turn-key" network systems are not well matched to the oceanographic research requirements and are too expensive. Basically, such systems have not changed significantly the way we do research at sea. This system, on the other hand, holds the promise of leading to fundamental changes to the way sea-going research is conducted. With the suite of services outlined in the table below, it is possible to imagine leaving expensive engineers ashore, and contacting them only if their services are needed. Problems can be solved through e-mail, VoIP (Voice over IP), or video teleconferencing. Data now routinely collected at sea, even when experts are not aboard, such as seafloor profiling data (e.g. SeaBeam) and Acoustic Doppler Current Profilers (ADCP), can all be sent ashore in near-real-time (latency of seconds). Scientists and technicians at the responsible institution can routinely (e.g. daily) quality control the data and routinely write the data to digital libraries. The outreach opportunities are substantial. Press conferences with limited or full quality video can be held when discoveries are made, or video can be routinely sent ashore.

Service	Typical Use
Voice	Telephone services for entire ship. Interconnection of ship's PBX with home institution's phone system.
Data	Transfer of large files of oceanographic data between ship and shore. Email
Web	Browsing for information. Database queries. Internet commerce. On-line banking for ship's complement.
Video	Teleconferencing. Store-and-forward high-quality picture transmission. Streaming video.

Table C.1 The IP suite of services available through *HiSeasNet*.

As an example of IP services that are now available, the ships are equipped with voice over IP (VoIP) gateways to interconnect the ship's PBX with the home institution's phone system. As a rule of thumb, with reasonable compression each call will take about 14 kbps of bandwidth including IP overhead. This bandwidth is required, however, only when someone is speaking - software deactive-

ates the circuit for the 60% of the time there is no conversation. So in reality an average of less than 6 kbps are used.

The savings afforded by the VoIP phone calls that would otherwise have to use INMARSAT are significant. During a recent one week period on the *R/V Roger Revelle*, the system logged 205 calls for a total of 8 hours for a savings of nearly \$1500 over the INMARSAT voice rate of \$3/min.

The systems and techniques developed for *HiSeasNet* will be directly applicable the goals of the Ocean Observatories Initiative, a NSF Major Research Equipment and Facilities Construction (MREFC) program, part of the ORION (Ocean Research Interactive Observatory Network) program to provide ocean observing capabilities to the research community through long-term platform in (and under) the oceans. With the deployment of a fleet of unmanned deep-sea platforms intended for long term deployments, the system proposed herein will give the land-based researchers full access to their instruments (all IP addressable) on these platforms and on the sea floor.

The goal of the proposed system is to provide basic Internet connectivity to the academic research fleet over the entire Atlantic and Pacific Oceans. While the impact on scientific work aboard ships is likely to be fundamental, the potential uses of *HiSeasNet* for education and outreach activities are substantial.

A good example of such use for integration of research and education is a recent participation of two middle school teachers in the NOAA Teacher at Sea program (See <http://www.tas.noaa.gov/>, and <http://www.ogp.noaa.gov/ootas/index.html>) aboard the *R/V Roger Revelle*.

Now in its 12th year, the program has enabled more than 360 teachers to gain first-hand experience of science at sea. Teachers can enrich their classroom curricula with a depth of understanding made possible by living and working side-by-side, day and night, with those who contribute to the world's body of scientific knowledge. The enthusiasm for learning generated between teachers and students is the biggest payoff of NOAA's Teacher at Sea program, where teachers from elementary school through college go to sea aboard NOAA research and survey ships to work under the tutelage of scientists and crew.

Ms. Debra Brice is a middle school science teacher at San Marcos Middle School in San Diego and Ms. Viviana Zamorano is a middle school science teacher at Escuela America in Arica, Chile. Debra and Viviana embarked on the *Revelle* from Ecuador on November 10, 2003 and traveled for three weeks to Arica, Chile.

While onboard, Debra and Viviana maintained daily logs, took photographs, interviewed scientists, and answered students e-mail. The highlight was a live teleconference between Debra and her class in San Marcos using *HiSeasNet*.

Below are some of her post-cruise comments:

"As a K-12 educator, being able to bring science as it happens into my classroom is a truly exciting teaching tool. My students were really excited at the idea that they could see me and talk to me in another hemisphere in the middle of the ocean (I was only 800 miles off the coast of Chile, but that is the middle of the ocean to them). They had never thought of actually going out in the middle of the ocean to study it, collect data and do experiments and they found it fascinating. They had questions about what it was like to be on the ship,

what we ate, where we slept, our daily work schedules. Everything was different and interesting and sparked their imaginations.

Using *HiSeasNet* to share the excitement of doing science, real time data and the value of collecting data at sea could be an invaluable tool in inspiring an interest in ocean science in today's youngsters.

As a teacher, the ability to use examples of ongoing research in my teaching makes it possible to give value to the skills and concepts I am teaching. *HiSeasNet* could be used to broadcast interviews with scientists, live broadcasts of experiments as they happen (watching a CTD cast or the results of a plankton tow for example) and even something as simple as giving a lecture on techniques of oceanography in my class could be augmented by a virtual tour of an oceanographic vessel by using the stationary cameras. My students are accustomed to watching Discover Channel videos about hydrothermal vent communities, but the difference between a video and actually seeing science as it happens is immense.

I am not sure if you wanted even more concrete ideas of how the *HiSeasNet* could be used? I am working on a website now that I will use as I try some broadcasts on an upcoming leg of the Melville. I am working on a virtual classroom in my classes. Interviews with scientists and tours of facilities that can be experienced in my classroom are examples of potential educational outreach by scientists that can be easily available to all schools and easy to access for the scientists also.

Please let me know if you need something more specific or detailed. Again, I really hope this helps with the acquisition of additional equipment. Ultimately my dream would be that through *HiSeasNet* my students and many others could watch as we go to the bottom of the Marianas trench. Imagine how exciting that would be, as exciting as when we watched men walk on the moon for the first time (only better reception!). Oceanography is really that exciting and *HiSeasNet* could bring that excitement to a lot of students."

Some additional comments from Chief Scientists, Engineers and Ship's Captain give an idea of the impact of this system and are included below.

I was very pleased with the system, especially since I had the pleasure of using the system on its maiden voyage. I'm glad to hear the system was moved, not only from the signal acquisition standpoint, but from a real estate standpoint since it did take up quite a bit of upper deck space.

With no insight on costs to operate the system, my views are only from the perspective of the utility of the connection (with no cost-analysis to bias those views).

* With the prevalent use of email to speak with program managers/funding agencies as well as coordination of multi-investigator experiments - the email connection allowed rapid response to fires on shore.

* We used the system for trouble-shooting equipment and to speak with a shore-side engineer who assisted in fabricating equipment. A video conference was also set up that allowed discussion of some of the measurement efforts.

* Connection on the home-front made it easier to be away.

I'm sure the proposers have covered their bases in all the various benefits such a system would have to the science community at large. One immediate application would be the utility of downloading satellite remote sensing data and/or exchanging data with other ships in adaptive sampling efforts.

Would the upgrades/expansion they have proposed be viable under the 2002 Shipboard Scientific Support Equipment proposal? If all \$'s dried up to support the system, I would support the use of Revelle or UC marine funds to support the continued operation as I believe when properly advertised to the broader marine community, it could be a money maker.

Having used the system now for a month, I can say that this is a clear advantage for seagoing work. Aside from the convenience of real-time email for all, which is wonderful, some obvious uses were employed on my cruise.

- 1) When repairing the broken load cell in the stbd crane, we tested it with a tester that read in tons, but did not state which type of tons. With web access, we tracked the tester to the mfg in Israel and determined that the unit measured metric tons in an hour or so. Knowing the wire tension was critical to our effort, and being able to find this information when the mfg. was closed (middle of the night in Israel) let us proceed with confidence.
- 2) We had several people working at sea on another project, bottom fish habitat in the Pacific Northwest. They were there because the collapse of rockfish fisheries brought about imminent closures of the continental shelves on the west coast that are being implemented as I write. The closure boundaries are based on our work, and we were able to produce the GIS files needed and ftp them off the ship in real time as we worked toward tight deadlines.
- 3) When we lost some coring gear, and needed to initiate immediate replacement, we were able to communicate that and discuss it with shore folks in real time, so that building of new gear, and shipping of some spare parts to us (held at MBARI in case we needed them) began hours after the gear was lost. Because of this, other cruises slated to use this gear immediately after ours, were not impacted by the significant loss we sustained.

I think this system should be implemented on all UNOLS ships ASAP. We used it for some utilitarian sorts of things, and it really helped. In the future I can envision much wider use for education, real-time science with investigators not on the ship. Perhaps near-time data processing ashore of some type and transmission of results to the ships.

Overall, the bandwidth provided by the ROADNet system has been a positive experience. As with any information channel it requires some discipline to use it effectively. Primarily the benefits have been administrative -- permitting us to continue to stay-in-the-loop and contribute directly to activities ashore (planning, proposal writing, etc) and operational -- grabbing update s/w from shore-based web-sites and checking upon remote data collection. So far, we have not envisioned a direct scientific benefit to our current operations, but that's because we've designed it to be self-contained and I suspect ideas on exploiting this new capability will begin to surface.

7/24 coverage is still a goal, not yet a reality. Moving the antenna/dome to atop the chart house has helped (As you are aware I was aboard during a Hawaii leg and the first trip following the SD port stop when the dome was moved from 02 forward to atop the chart house). Even after the move, depending upon the heading the signal was blocked enough by the main mast to disrupt service. On the one hand, this is not really a problem -- everyone just has to wait a bit for email etc --, but it does create an additional operational interaction in that it can prompt requests to the bridge to adjust the heading 10-20 degrees to regain the signal. I would suspect this might become tiring for the mates after some time. It appears that there is not much that can be done about the main mast interference so if continuous coverage is the goal it will require some additional effort or gear (two radomes?).

There should probably be some thought put into a set of protocols/procedures for the web-cams -- perhaps only on-line when the Chief Scientist and Capt. determine that something is worthwhile for the public. I guess the best way to say this is that when at sea the lab becomes your office. Even ashore in your office you cannot have all the activity and transactions being broadcast. Additionally, the Capt. expressed some concerns -- not sure of the nature -- about 24/7 web-cam of the after-deck.

In addition to the 7/4 coverage it would be best for SIO if wide spatial coverage was possible -- to avoid the negative reaction of ship users when moving out of the coverage area. It did appear that the ROADNet was a morale booster for the crew. Not sure how helpful these comments are in regards to a proposal submission, but our cruise's productivity and effectiveness was been improved by this capability.

The satellite communications upgrade was a major improvement to our student cruise. In the future I can see expanding the effectiveness of my seagoing course significantly using this system. In addition to the 20 undergraduate and graduate students I was able to bring out to sea for hands on experience for 5 days, we could have a larger group of students back at campus deriving at least some of the lessons to be learned by going to sea. I think this will be a very powerful outreach and educational tool, especially for undergraduate and K-12 education.

Thank you for your note on proposed improvements to the Satellite Internet System. These days it's not hard to explain to anyone the value of an Internet connection on land. At sea the value is vastly greater since other means of communications are often much less practical. Of course I don't know the costs relative to other proposed investments, but I can say that the Satellite Internet System was of tremendous value during our recent Kauai Experiment. I expect that anyone that has sailed on a ship with that capability would sorely miss it on another vessel that lacked it. Extending coverage to the Kilo Moana and for the Atlantic on the Revelle and to smaller UNOLS vessels would seem to be a very worthwhile investment.

We found the real-time satellite link extremely useful while at sea on Revelle in September 2002 and wish it were installed on all UNOLS ships. We used it to exchange information with our home base to obtain things we found a need for at sea and hadn't brought along. I tried to get Revelle for a forthcoming cruise in the North Pacific but couldn't owing to its sojourn to the south. We will be launching a drifter that communicates hourly via Iridium and would have used the link to get the messages from a computer in Seattle. Without this link, we've had to design a system for making calls and are finding it far less reliable than Revelle's link.

On a more personal level, we were on Knorr in the Black Sea during the Iraq war and couldn't get even minimal news because WHOI had cut off their previous new service to save money. Everyone in my group was wishing they were on Revelle.

Geologists aboard The R/V Revelle asked the shore based Geophysical Analyst for some advice in processing their four channel seismic reflection data. 73MB of data were transferred from the ship to a shore based computer so that the analyst could examine the problem dataset. The 2.75 hours of seismic data took two hours to transfer.

The analyst noticed that one of the seismic traces was inverted in polarity and that the stack (addition) including the inverted trace was significantly inferior. As a result of this interaction between ship and shore based personnel, the seismic image produced on the ship was significantly improved.

[Note: At this time the ship to shore circuit speed was 64 kbps or 8 kbytes/sec. So 2 hours for transfer of a 73 Mbyte file means that in practice the circuit was reaching its theoretical capacity.]

Having this system in place is very good for crew moral. Being able to communicate via e-mail and telephone is a big boost. We have used the system to down load chart corrections. Using the system to obtain up to date weather, not otherwise available aboard.

- Crew are using the system to "pay bills" on line
- Engineers have used the system to find spare parts on line
- I have used the internet to research products for the ship.
- Down loading information not other wise available from Ships Scheduling ("its on the web")

We are still learning what is available. Am certain there will be more uses of the system as we become more familiar with it.

Perhaps I can add a few more SCG uses of the system. Off-the-cuff, these are a few things I have already done from sea since the system became available. This does not include the list of things I have seen scientists do.

- Update embedded code on shore side equipment from sea (the VoIP box in particular when we were setting it up)
- Download latest patches, drivers, etc.
- Automatic update for online virus checking cleaning
- Install complex software on the ship while on shore
- Reboot, reset, or reconfigure shore side services from sea
- Troubleshoot mail/other issues immediately from ship (especially over weekends)
- Backup and restore important configuration or source files between ship and shore in real time
- Exchange configurations, settings, code, binary files in real time, solving problems in hours, not days.
- Send multibeam data from transit legs to scientists leaving the ship.
- Send larger photos to shore to explain ship resources (a picture is worth 1000 words sometimes)
- Track packages due at the next port stop
- Troubleshoot equipment with tech support (over VoIP)
- Update/review shore-based documentation in realtime (via our trouble ticket system)
- Test network routing and service issues from shore side without the need for someone on shore to be available.

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